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USE OF SHAPED CHARGES IN MINING OPERATIONS

E. Contestabile, T.R. Craig and R. Demers
Canadian Explosives Research Laboratory

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USE OF SHAPED CHARGES IN MINING OPERATIONS

by

E. Contestabile*, T.R. Craig** and R. Demers**

ABSTRACT

This report describes the effective use of shaped charges in the Elliot Lake Mine Roof Stability Project to remotely remove the heads from the roof bolts. With a slight modification, these same shaped charges are being recommended for use to the Brunswick Mining and Smelting Corporation Limited (Mining Division), to cut the steel cables that support the roof of the mine.

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USAGE DE CHARGES CREUSES DANS LES EXPLOITATIONS MINIÈRES

par

E. Contestabile*, T.R. Craig** et R. Demers**

RÉSUMÉ

Ce rapport montre l'utilité effective de charges creuses employées lors du projet de la stabilité du toit à la mine d'Elliot Lake pour enlever à distance les têtes des boulons d'ancrage.

Moyennant une simple modification, ces mêmes charges creuses sont à recommander pour couper les câbles d'acier supportant le toit de la mine à la Brunswick Mining and Smelting Corporation.

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INTRODUCTION

The Canadian Explosives Research Laboratory (CERL) often receives requests to cooperate in solving problems encountered in private industry or other sectors of the government. CERL is equipped to design and test explosive and pyrotechnic devices and the policy is to treat each case individually. The first case reported evolved from a request from a sister laboratory at Elliot Lake. Their intent was to remotely remove the heads of roof bolts as part of a mine roof stability project. The device designed for this use was 100% effective in the laboratory and 80% effective in the mine. The second case reported results from a request from a private mining company knowledgeable of the Elliot Lake project. Their wish was to remotely cut steel cables that support the mine roof. The project was first treated as presenting a new problem however the solution was resolved to be very similar to the former.

THEORY

Shaped Charge Effect (Munroe-Neumann Effect)

Shaped charges were first used as hollow charges, that is, an explosive with a depression countersunk in it. Later, it was found that better penetration could be achieved if the depression was lined with an inert material. Figure 1 shows the essential components of a shaped charge. With an unlined charge the focused action is due to incident and reflected shock waves that cause a mass of dense gas to move with great velocity. In the case of the lined charge, the action is due to the jet formed by the collapsed liner.

The mechanism of the lined charge is that of the collapse of the liner as the detonation wave impinges on the cone. When the detonation wave reaches the apex of the cone, the very high pressure produced causes the outside of the cone to move inward at very high velocities. In so doing, the cone material basically divides in two. The material from the inside surface flows to form a jet which originates at the apex and travels along the axis at speeds from 2000 m/s to 1000 m/s. The material from the outside surface of the cone flows toward the axis to form a slug that travels at speeds from 500 m/s to 1000 m/s. It is the jet that is responsible for the penetrating effect. Thus, it is seen why lined shaped charges are more destructive than unlined ones. The high velocity jet pushes aside the target material by pressing against it with pressures of the order of 10 MPa. As reported by Cook (1), the penetrating power (hole volume and depth) is directly proportional to the detonation pressure with the assumption that the explosives used are ideal and moreover that they possess very short reaction-zone lengths. Very little effect is produced by explosives having detonation velocities of 5000 m/s or less. The maximum effect is achieved when

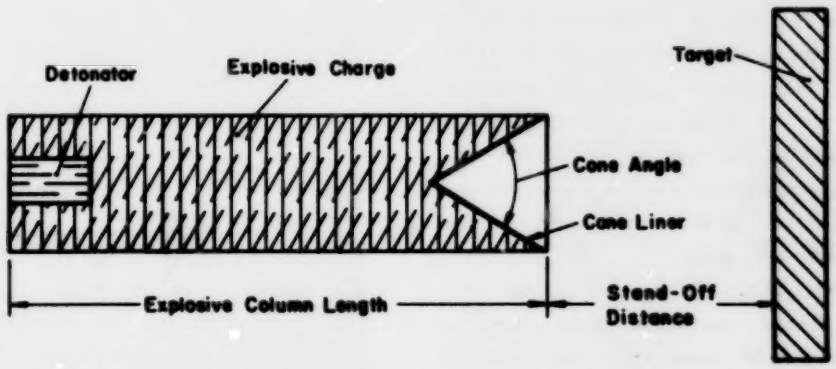

Fig. 1 - Essential components of a shaped charge

the detonation head is fully developed. This is considered to occur when the charge length is equal to at least three charge diameters. Then the optimum energy match of the liner with the explosive occurs when the mass of the detonation head, which carries the forward momentum necessary to collapse the liner and form the jet, is equal to the mass of the liner. From reference (2) some experimental results for lined shaped charges are:

1) A velocity gradient exists along the axis of the jet with the tip moving fastest and the slug at the tail end slowest. The velocity of the jet increases (never exceeding twice the detonation velocity) with a decrease of the cone angle.
2) Even though material from the jet is captured by the target, the diameter of the hole produced in the target is always larger than that of the jet, with the holes being smaller in hard materials than in soft ones.
3) The penetration into the target is nearly independent of the target material since the high pressure at the point of impact is much greater than the yield point of most materials.
4) The penetration into a given target first increases and then decreases as the stand-off distance between the charge and the target increases. With a given liner there is an optimum stand-off distance that should be determined experimentally. As the stand-off distance is increased the jet becomes extended. This causes an increase in penetration and a decrease in the diameter of the hole produced. A further increase in stand-off distance causes the jet to break up both axially and radially thereby increasing its cross-sectional area and causing its polyfurcation before striking the target. The result is the loss in penetrating effect.
5) The best results are obtained by using steel or copper liners. Aluminum gives poor results. Tests have shown that the depth of penetration is greatest with metals of highest density. However, ductility also plays a major role. As the depth of penetration decreases, the diameter of the hole increases and vice versa. It has been found that the hole volume is practically constant and correlates with the total energy of the explosive.

EXPERIMENTAL

Elliot Lake Mines Roof Stability Project

As part of the project on roof stability in the Elliot Lake Mines, CERL was asked to devise a method to safely remove roof bolts to induce roof failure (see Appendix A). The bolt pattern was comprised of 800 bolts with the bolts being about 1.5 m apart. The item used to remove the bolt heads must comply with the following requirements:

1) Sections of the roof support system must be removed as required and from a remote location.
2) The device used must not directly contribute to roof failure.
3) The device used must not produce excessive shrapnel that would disrupt other devices.
4) The device must remain operational in a mine environment for several months.

With these restrictions as guidelines, a series of tests were begun. Figure 2 shows a typical roof bolt. As mentioned in the request, the roof bolts are installed with about 20 N-m torque which translates to 3.6 T. Thus if the

Fig. 2 - Typical roof bolt

head of the bolt could be removed, the tension and thereby the roof support, would be eliminated. The following tests were applied to bolts in a set-up where the bolts were mounted so as to be under 3.6 T tension.

1) Due to its use in mining operations, detonating cord was chosen for the first test. Several turns of detonating cord, ranging from 10 g/m to 50 g/m, were wrapped around the head of the bolt. Initiated with an electric blasting cap, only the 50 g/m detonating cord deformed the head of the bolt which otherwise remained intact.

2) An explosive that has proven to remain reliable over long periods of time is Composition C-4 (or simply C-4). It is white in colour and is composed of 90% RDX (cyclo-1,3,5-Trimethylene-2,4,6 -trinitramine) and 10% plasticizer (polyisobutylene) which gives it a putty-like texture. C-4 is relatively insoluble in water, has a high detonation velocity of 8050 m/s unconfined (2.5 cm diameter, ρ = 1.59 g/cc) and is very insensitive to mechanical impact and frictional loads. 100g of C-4 was shaped around the head of a roof bolt and fired with a blasting cap. No damage to the head resulted.

3) Another explosive that would suit the humid environment found in a mine is Detasheet (3), a DuPont product. Detasheet C, green in colour, is made with 63% PETN (pentaerythrol tetranitrate), 8% nitrocellulose and plasticizer. It is available in different shapes such as sheet, cord or ribbon. It has indefinite storage life at room temperature, a density of 1.48 g/cc, a detonation velocity of 7000 m/s and is fairly insensitive to impact and friction. A piece of 3 mm thick Detasheet was cut in the shape of an isosceles triangle having a base of 5 cm and a height of 8 cm. The base of the triangle was taped to the side of the bolt head and it was initiated by a blasting cap fastened to the apex of the triangle. On firing the blasting cap, the linear shock wave generated impinges on the side of the bolt head. A result of the test showed damage to the head, however it still remained well attached to the shank of the bolt.

4) After these tests it was decided to use shaped charges since increasing the amount of explosive would possibly contribute to roof failure. Having recently cooperated with the Royal Canadian Mounted Police (RCMP) on a project to disrupt bombs, several shaped charges were available for evaluation. The first to be tested was a cylindrical type 2.5 cm long and 2.5 cm diameter made of tin and having a copper liner. Using the explosive C-4 with stand-off distances from 0 to 10 cm varying results were obtained. For example, at a stand-off distance of 4 cm, the hole produced on the head of the roof bolt was 1.5 cm diameter and 3 cm deep. As seen from Fig. 3, the head was not removed. Best results were obtained when the shaped charge was placed in contact with the bolt. In this test the bolt head normally fragmented into three pieces with one always remaining attached. The hole diameter, however, was not large enough to consume the shank of the bolt and cause the head to detach. Similar results were obtained using the same shaped charges loaded with the German explosive DM 12. This explosive, like C-4, is easily moulded since its consistency is also similar to that of putty. Light brown

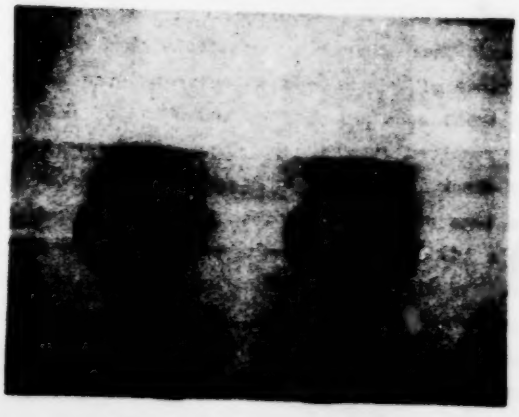

Fig. 3 - Damage to bolt heads from cylindrical shaped charges 2.5 cm long and 2.5 cm diameter

in colour, it is composed of 86% PETN, 1% calcium sterate and 13% oil and grease.

Two other shaped charges that were available for evaluation were a 5 cm diameter by 10 cm long cylindrical, copper lined shaped charge and an Ireco "Iretap". The 5 cm diameter shaped charge with a 7.5 cm stand-off distance proved to be very effective. However, due to the high explosive content it produced excessive shrapnel and it was anticipated to contribute to roof failure. The "Iretap" is used to tap electric, open hearth or blast furnaces by making a hole through the taphole plug or skull. Even though it contained less explosive than the above-mentioned 5 cm diameter shaped charge, it easily removed the head from the bolt. The disadvantages of this unit were its high initial cost and the requirement to modify it so that it could easily be mounted on the head of the bolt.

A linear shaped charge secured to the side of the head of the roof bolt was also tested. The result was partial damage to the head. However, part of the head always remained attached to the bolt shank.

Since the 2.5 cm diameter shaped charge was too small and the 5 cm diameter shaped charge was too energetic it was decided to design a shaped charge that would fit between the above two. Various charges were prepared at the laboratory and tested. The optimum shaped charge size for the job in question was found to be the one shown in Fig. 4. Figure 5 shows a cross-section of this charge with the electric blasting cap in place. These charges, installed with a stand-off distance of 1.5 cm easily penetrated the head of the bolt, consumed part of the shank of the bolt and resulted in the separation of the head from the shank. As noted in Fig. 5, the cylinder and the legs of the shaped charge were made from tin while the cone liner was shaped from copper. Appendix B discusses the loading procedure of these charges and their installation on the heads of the roof bolts. The action of the shaped charge often caused the head of the bolt to split in two or three pieces. However the trajectories of these pieces were rather short and imposed no serious problem to the adjacent charges. Figure 6 shows

Fig. 4 - Shaped charge used at Elliot Lake mines roof stability project

Fig. 5 - Cross-section of shaped charge used at Elliot Lake roof stability project

the typical action of the shaped charge to the head of a bolt. The head is split in two pieces and is separated from the shank of the bolt.

Permission was sought and was granted by the Mining Health and Safety Branch of the Ontario Ministry of Labour to use the explosive C-4 underground. The Chief Inspector of Explosives then gave permission to load the shaped charges at the Elliot Lake Laboratory facilities according to the procedure outlined in Appendix B.

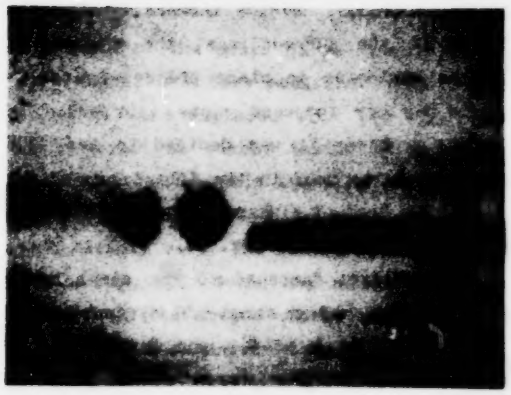

Fig. 6 - Head split in two and separated from the shank of the bolt

Dr. D.F.G. Hedley, Project Leader of Elliot Lake mines roof stability project, reported in a private conversation that 80% of the bolts had their heads removed by the shaped charges. He also made available Fig. 7 which shows the shaped charges installed to the heads of the roof bolts in a mine.

Brunswick Minirg Cable Cutting Project

The request for advice on cutting steel cable for Brunswick Mining and Smelting Corporation Ltd. is shown in Appendix C. Two, 16 mm (0.625 inches) diameter steel cables are grouted into each hole which is drilled on a 2 m by 2.5 m grid pattern. As mining proceeds upward it is necessary to cut the cable. Often the cable becomes entangled with the fallen rock and remains under tension. This situation presents a problem for the person who is required to cut the cable. The cable can easily snap once it is cut and may cause injury. The requirement is for a simple system that will easily cut the cable from a remote location and with a minimum amount of explosive. The number of cables to be cut per day would be about thirty so that the cost should be considered.

Since the mine uses detonating cord, an attempt was made to use it to cut the cable. Three turns of 50 g/m (200 grains/ft) detonating cord were wrapped around the cable. The result of firing it with an electric blasting cap left the cable completely intact. DuPont's Detaprimes

Fig. 7 - Shaped charges installed in a mine

and Detasheet both suitable for the mining environment were also tested. Their actions caused some of the strands to break, but the results were not consistent. The same result was obtained using C-4 explosive. Figure 8 shows the test set-up and Fig. 9 shows the result. In this case none of the strands were cut, but were merely deformed. This test did not give reproducible results often separating the cut strands over a length of 0.5 m (see Fig. 10).

In order to increase the reliability of this system, the amount of explosive used would have to be increased. Beside increasing the cost and damage to the surroundings, the problem of holding the explosive in place presented itself. This would further increase costs. In order to avoid these problems it was decided to test the shaped charge units used in the Elliot Lake Mines Roof Stability Project. Such a charge, attached to a roof bolt is shown in Fig. 11.

The charges fastened to the steel cable with masking tape had a stand-off distance of 3 cm. Loaded with 60 g of C-4 and fired with an electric blasting cap the charge caused most of

Fig. 8 - C-4 on the steel cable

Fig. 10 - Result of the action of C-4 on the steel cable note strand separation

Fig. 9 - Result of the action of C-4 on the steel cable

Fig. 11 - Shaped charge installed to a roof bolt

the strands of the cable to be cleanly cut. The shaped charge was then modified. The two sheet metal legs were replaced with two wire legs so that it could be easily installed on the cable with no stand-off. This installation is shown in Fig. 12. Installed in this manner the cable was always cleanly cut. The result of such a test is shown in Fig. 13. Next, the amount of explosive used to load the shaped charge was varied so as to determine the minimum amount required to cut the steel cable. This minimum was found to be 30 g. It is recommended, however, that at least 40 g of C-4 be used to cut the cable consistently. Appendix D describes the loading and installation of the shaped charges to the steel cable.

Before this operation is undertaken it is necessary to obtain permission from the provincial and federal authorities. The New Brunswick Occupational Health and Safety Commission is responsible for permitting use of explosives in the mine environment. The commission will thus rule on the use of C-4 in the mine. If the shaped charges are to be loaded at the mine site it is necessary to seek permission from the Explosives Branch of the federal government. The Explosives Branch will issue a factory license once the requirements outlined in the Explosives Act are met.

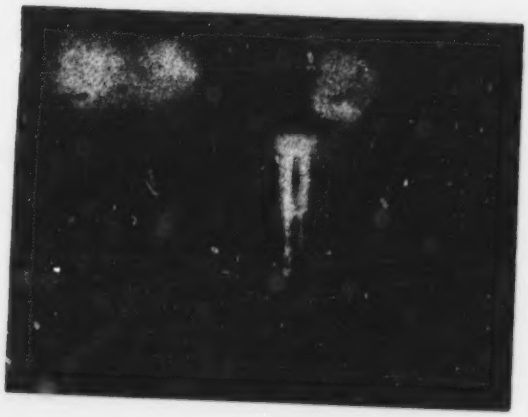

Fig. 12 - Shaped charge installed to steel cable

Fig. 13 - Result of the action of the shaped charge on the steel cable

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2. Fedoroff, B.T. and Sheffield, O.E. Encyclopedia of Explosives and Related Items, Vol. 4, Picatinny Arsenal, Dover, New Jersey, U.S.A., 1969.

3. Detasheet - flexible explosive, E.I. DuPont de Nemours & Co. (Inc.); Explosives Products Division Military Specialist Sales, Wilmington, Delaware.

APPENDIX A

REQUEST FROM ELLIOT LAKE LABORATORIES

Government of Canada / Gouvernement du Canada

MEMORANDUM NOTE DE SERVICE

TO / A: Ron Vandebeek

FROM / DE: D.G.F. Hedley

SECURITY - CLASSIFICATION - DE SÉCURITÉ

OUR FILE/NOTRE REFERENCE

YOUR FILE/VOTRE REFERENCE

DATE: September 2, 1980

SUBJECT / OBJET: TESTING OF ROCK BOLTS

I gather that Glen Larocque has discussed with you some testing I would like done on knocking the heads off bolts with blasting caps.

As part of a project on roof stability in the Elliot Lake mines, I want to induce roof failure in a few test stopes and investigate various monitoring systems as warning devices. The stopes have already been mined and the rock bolts installed. Up to 800 bolts will have to be blasted in stages and I want to be sure the heads will come off the bolts since nobody will be able to enter the stope after the test begins. A similar type experiment was conducted at the White Pine mine in Michigan some years ago and attached are the relevant pages of the report on this test. Unfortunately they did not specify the type of blasting cap used. Also, they drilled holes in the bolt head,to take a blasting cap, prior to installation of the bolts which cannot be done in this case since the bolts have already been installed.

I have shipped down to you, by CP Express, six 3 ft. long roof bolts with shells and plates. When installed these bolts would normally be torqued to 140 ft. lbs. or 3.5 tons tension. If possible I would like answers to the following questions:

1. What type of blasting cap is required to knock the heads off the bolts? (the mine uses CIL products).

2. What method of attachment should be used to connect the blasting cap to the bolt head?

3. What can be placed over the bolt head to prevent shrapnel?

Please call if you have any questions and thanks in advance for your help.

Dave.

DGFH/caj
Attach.

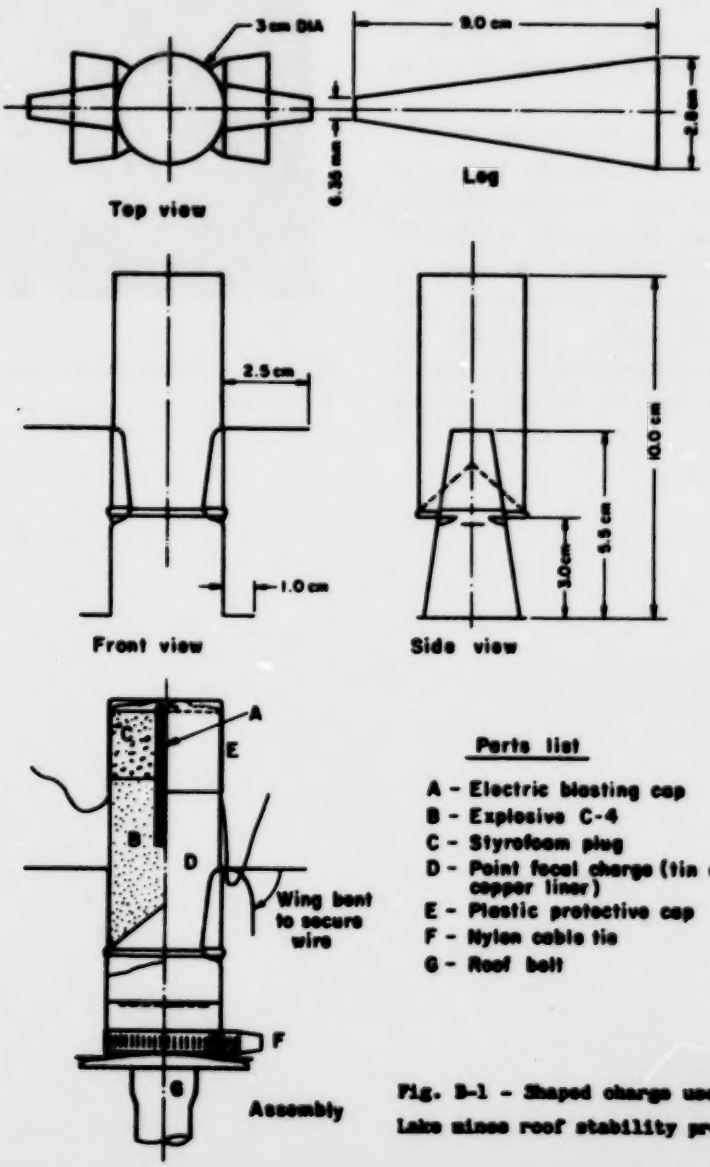
APPENDIX B

LOADING AND INSTALLING THE SHAPED CHARGES TO THE ROOF BOLTS

Permission was obtained from the Chief Inspector of Explosives at the Explosives Branch to load the charges at the Elliot Lake laboratory facilities. The clean area provided was restricted to everyone except for the personnel involved with the loading. Other safety considerations such as not permitting smoking and only allowing the use of non-sparking tools were strictly adhered to. The loading procedure is outlined below.

If the explosive has been stored in a cold area it may be necessary to either knead and manipulate the C-4 or to store it at a temperature of about 18°C for a few hours to soften it. This makes the packing much easier. Because, C-4 can be quite sticky, it is advisable to begin operations with clean hands.

The shaped charge container (Fig. B-1) will hold a maximum of about 70 g of C-4. However, in order to assemble the styrofoam plug the



Parts list

- A - Electric blasting cap
- B - Explosive C-4
- C - Styrofoam plug
- D - Point focal charge (tin cylinder, copper liner)
- E - Plastic protective cap
- F - Nylon cable tie
- G - Roof bolt

Fig. B-1 - Shaped charge used at the Elliot Lake mines roof stability project

charges are normally loaded with about 60 g of C-4. Loading begins by placing a small amount of C-4 in the container and using a 1.0 cm diameter by 20 cm long wooden dowel one end of which has been sharpened to a 2 mm diameter point, to firmly pack the explosive around the cone. Additional C-4 is added and packed with the other end of the wooden dowel. This procedure is repeated until the required amount of explosive is loaded and levelled with the use of the fingers. The styrofoam plug is then inverted and held in place with masking tape or plastic cap. A wooden dowl having a diameter equal to or slightly smaller than that of the blasting cap is then guided through the hole in the styrofoam plug and a depression is made in the C-4 to facilitate the insertion of the blasting cap.

The installation to the head of the roof bolt is quite simple. The legs on the shaped charges are designed to give the proper stand-off distance when they rest against the shoulder of the bolt. Using a nylon cable tie, the charge is securely fastened to the head of the bolt. The blasting cap may now be inserted. Friction will hold the blasting cap in place, however, a plastic protective cap can be used to seal the blasting cap in the container. Also the blasting cap wires can be looped to the tin rings on the side of the shaped charge. These rings can also be bent to hold the rest of the wires close to the mine roof, away from falling debris. Before the charges are fired it is important to check that all charges are aligned with the head of the bolt. This assembly is shown in Fig. B-2.

Fig. B-2 - Shaped charge installed to the head of a roof bolt

APPENDIX C

REQUEST FROM BRUNSWICK MINING

Brunswick Mining and Smelting
Corporation Limited (N.P.L.)
Mining Division
P.O. Box 3000
Bathurst, New Brunswick E2A 3Z8

Tel: 506-546-6671
Tlx: 014-24582

brunswick mining

1982 11 30

Mr. R. Van Debeek
Department of Energy, Mines and Resources
CANMENT
Canadian Explosives Research Lab
555 Booth Street
Ottawa, ON
A1A 0G1

Dear Mr. Van Debeek:

Further to our telephone conversation of the 26 November concerning the possible cutting of cables using explosives, the following details may give you an idea of what we need to do.

1) The cables to be cut are 5/8" diameter, 7 strand, stress-relieved, de-greased, with an utlimate strength of 29 tons.

2) Two cables approximately 60 feet long are grouted into a drill hole in the roof of the stope, to improve ground stability.

3) As mining proceeds upwards in 16 feet lifts, it is necessary to cut the cables. To date we have tried hydraulic cutters and torches but with little success.

Therefore we would be most interested to hear if you feel it is possible to break these cables with explosives.

We look forward to your comments.

Yours truly

P. J. Hurley
Project Engineer

c. D. H. Waters
B. W. Jamieson

DEC - 8 1982

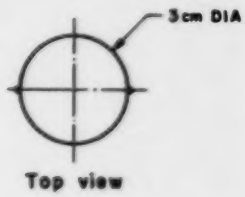
APPENDIX D

LOADING AND INSTALLING THE SHAPED CHARGES TO THE STEEL CABLE

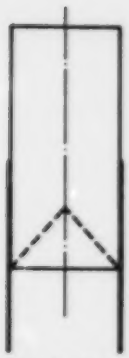
Once permission has been obtained from the Explosives Branch, a clean area restricted to everyone except for the personnel involved in the loading must be made available. This area must be segregated from other working areas, smoking must be restricted and only non sparking tools be permitted in the loading operation. The loading procedure is as follows.

If the explosive has been stored in a cold area it may be necessary to either knead and manipulate the C-4 or to store it at a temperature of about 18°C for a few hours to soften it. This makes the packing much easier. Because C-4 can be quite sticky, it is advisable to begin operations with clean hands.

The shaped charge container (Fig. D-1) will hold a maximum of about 70 g of C-4. However, in order to assemble the styrofoam plug, the charges are normally loaded with about 50 g of C-4. Loading begins by placing a small amount of

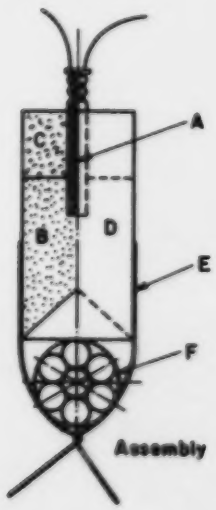


Top view



Front view

Side view



Assembly

Parts list

A – Electric blasting cap
B – Explosive C-4
C – Styrofoam plug
D – Point focal charge (tin cylinder, copper liner)
E – Wire
F – Steel cable, 16mm DIA, 7 strands

Fig. D-1 - Shaped charge recommended for use by Brunswick mining

C-4 in the container and using a 1.0 cm diameter by 20 cm long wooden dowel one end of which has been sharpened to a 2 mm diameter point, to firmly pack the explosive around the cone. Additional C-4 is added and packed with the other end of the wooden dowel. This procedure is repeated until the required amount of explosive is loaded and levelled with the use of the fingers. The styrofoam plug is then inserted and held in place with masking tape or a suitable plastic cap. A wooden dowel having a diameter equal to or smaller than that of the blasting cap is then guided through the hole in the styrofoam plug and a depression is made in the C-4 so as to facilitate the insertion of the blasting cap.

The installation to the steel cable is straight forward. Simply place the cone end of the shaped charge against the cable with the two wire legs straddling it. Then twist the wires tightly together so that the charge does not slip. It is important that the charge be installed perpendicular to the cable. The blasting cap may now be inserted. Friction with the styrofoam plug will hold the blasting cap in place, however, a suitable plastic protective cap can be used to seal the blasting cap in the container (Fig. D-2). The blasting cap wires may also be secured to the wire legs of the shaped charge.

Fig. D-2 - Shaped charge installed to steel cable

POOR

QUALITY

ORIGINAL